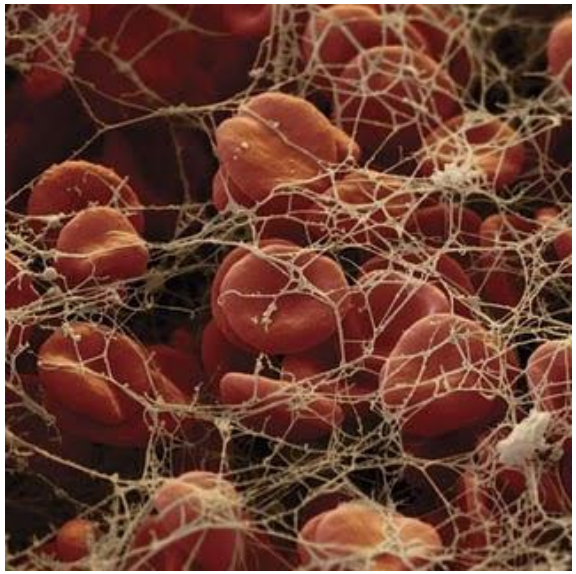
Regeneration and Remodeling of Materials

http://www.foxnews.com/story/0,2933,307739,00.html



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Outline

- Program overview
- Regenerative coatings
  - acrylic system
  - surface microvalves
- Dynamic polymer
  - bi-phase system
  - regeneration experiments
- Multiscale scaffolds
- Summary

Autonomous Materials Systems Group

Regeneration & Remodeling Team

Ryan Gergely (AE)

Windy Turchyn (Chem)

Brett Krull (MatSE)

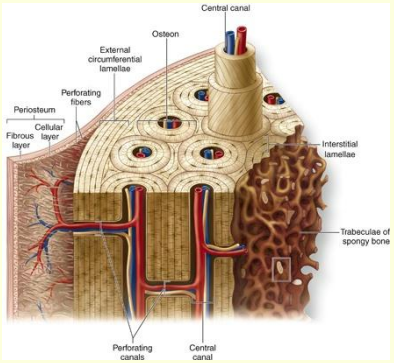
Concepts and Motivation

Regeneration and Remodeling in biology:

Tree skink lizard

Linckia starfish

Human Bone



Key Features:

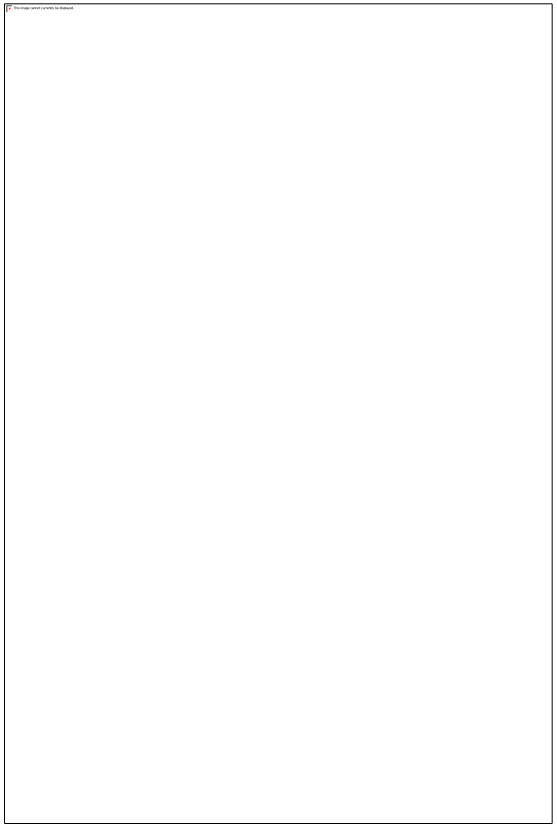
- Large scale damage volume
- Repeatability and Reversibility
- Orders of magnitude change in properties
- Autonomy
- Stress activation

Benefits:

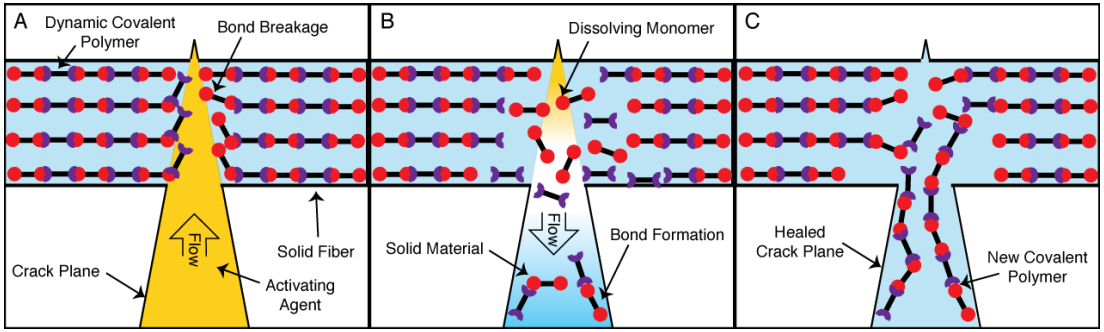
- Selective restructuring
- Response to environmental stimuli
- Reduction in parasitic weight
- Anti-aging
- Self-repair

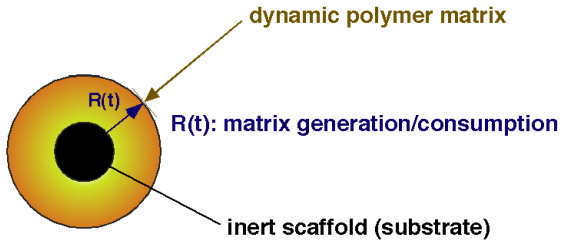
Overview

Regeneration in biology:

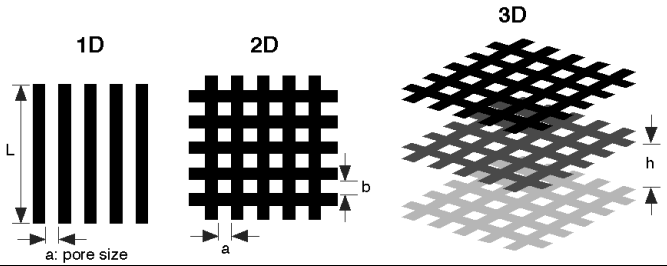


Our approach: *Dynamic polymers*





+ inert scaffolds



GOAL: To develop bio-inspired composite material systems that regenerate and remodel in response to environmental stimuli.

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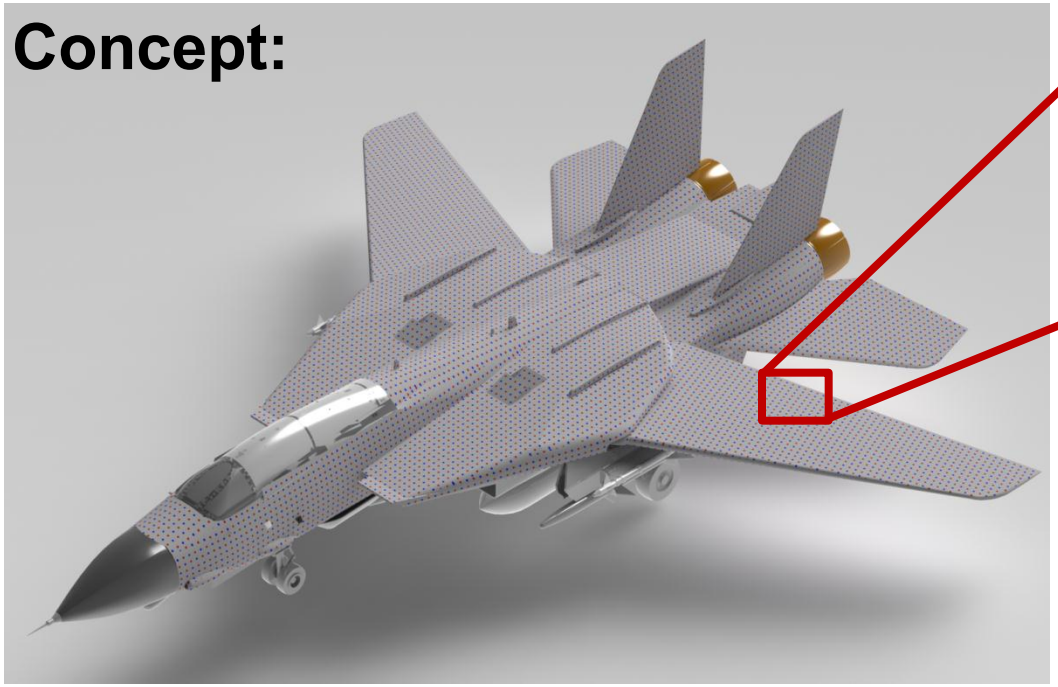
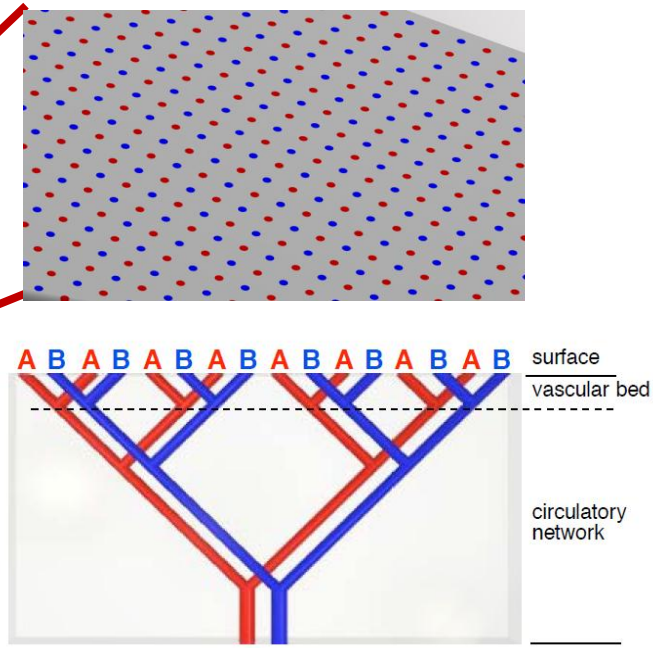
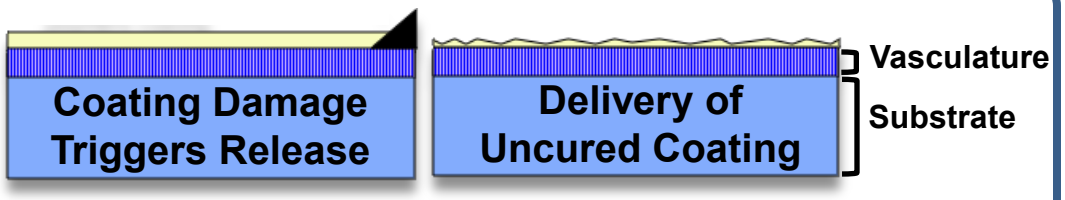
Coating Regeneration



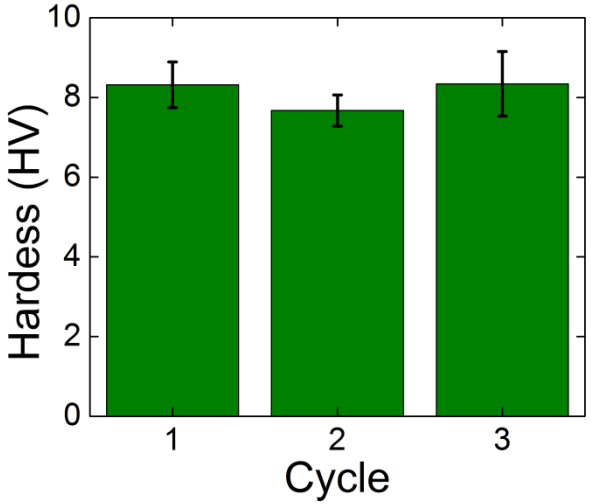


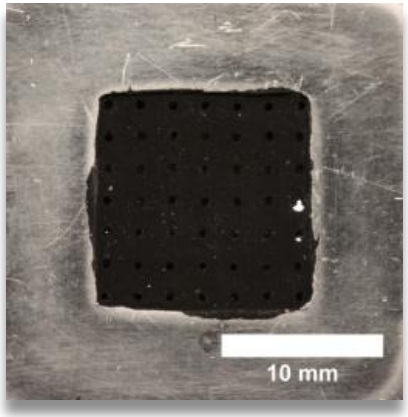


- Current healing technology targets small scale damage (cracks)
- Extensive damage is difficult to heal
- Channel blockage is a challenge

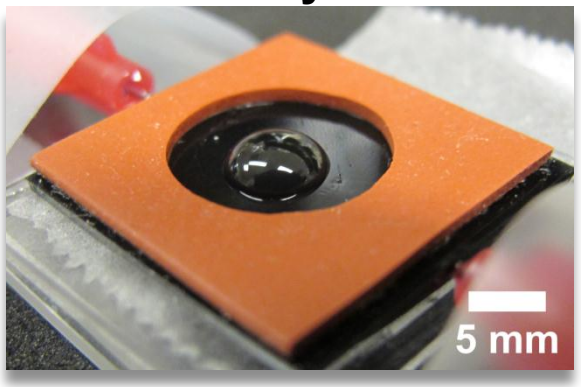
Surface Microvalves

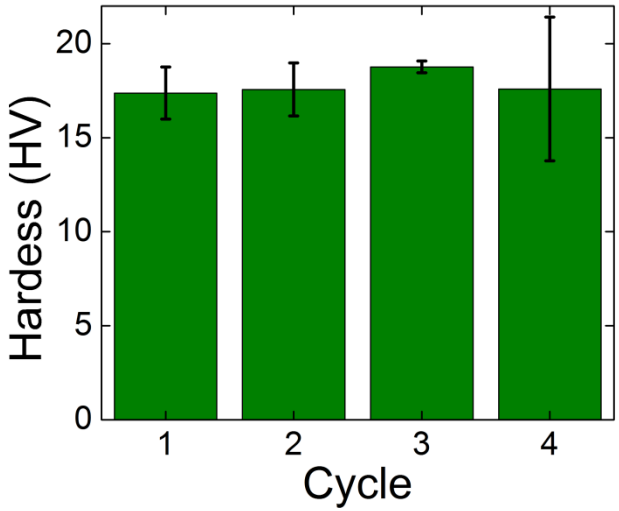
Prior Results





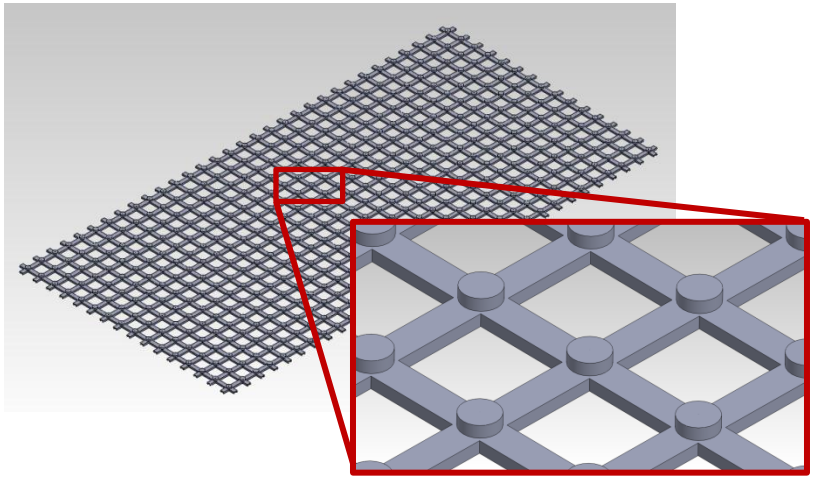
Valved Pores Prevent Curing into Delivery Network



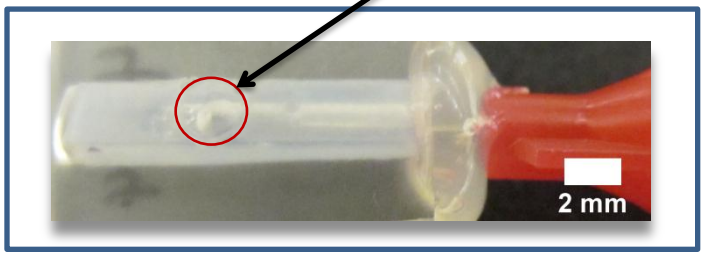


Valve Network Design

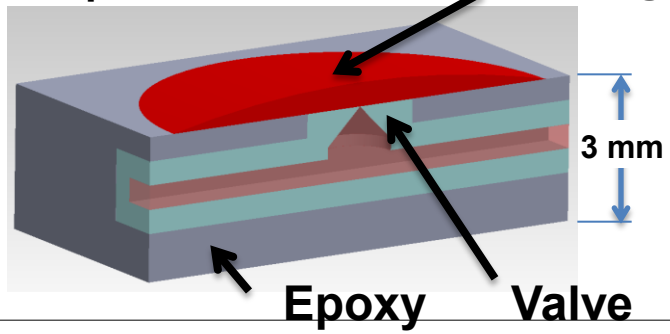
valve network



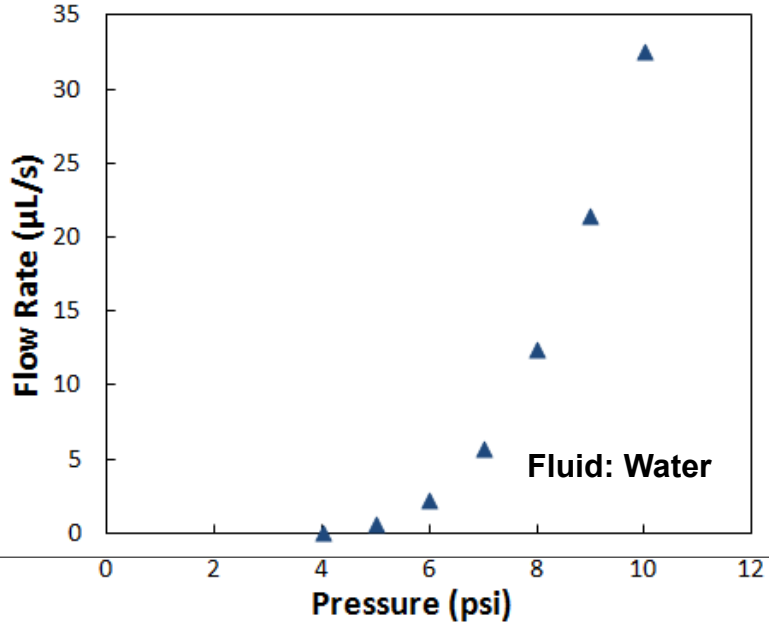
Valve



Sample Cross-section



Valve Flow Characteristics



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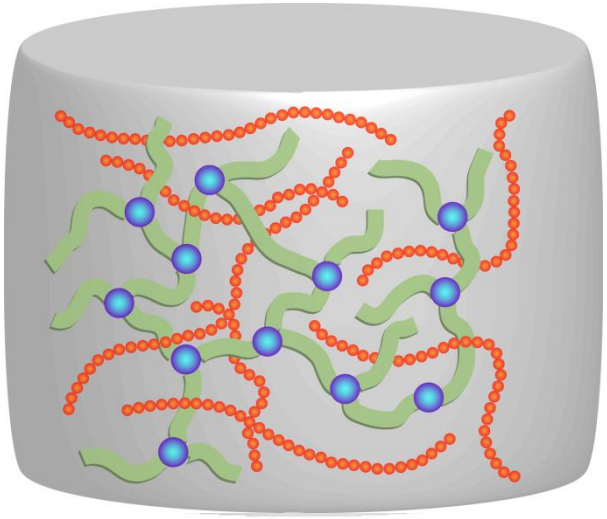
Bi-Phase Chemical Resin



Acylhydrazone end-functionalized PEG oligomer

Tri-aldehyde crosslinker

Methacrylate liquid monomer (HEMA)

Sol

•**Concept:** Low viscosity solution for easy delivery via microvascular networks

•**Design:** Consists of gelator components in liquid monomer "solvent"

Gel

•**Concept:** Rapid viscosity increase to a semi-solid as first transition

•**Design:** Acid catalyst initiates gel formation at time, t_1

Polymer Solid

•**Concept:** A second stage transition for recovery of mechanical strength of damaged region

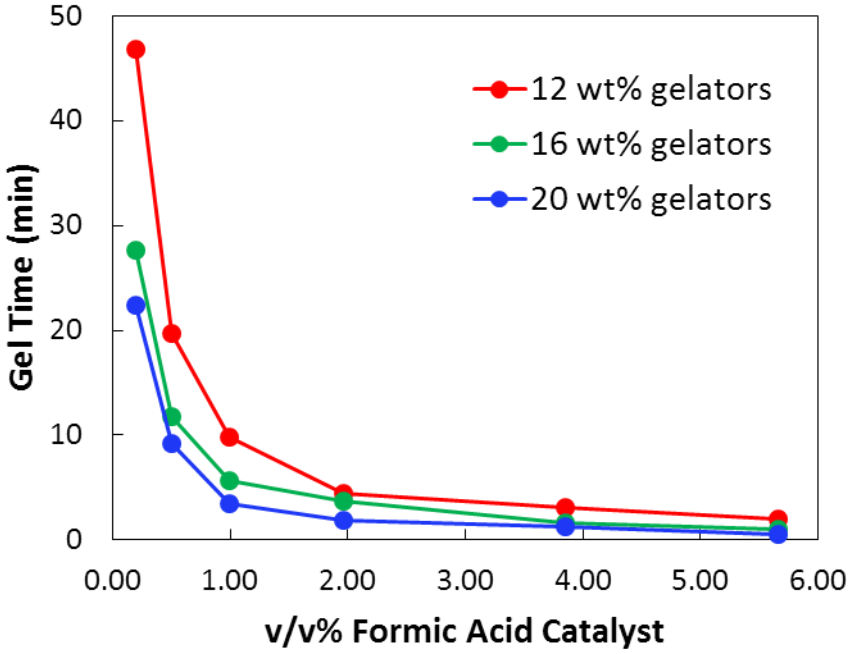
•**Design:** Monomer (HEMA) polymerizes at time, t_2, by initiator/promoter

Deng, et al. *Macromolecules*, 2010, *43*, 1191-1194

Individually Tunable Chemistries

t_1 Gel Time

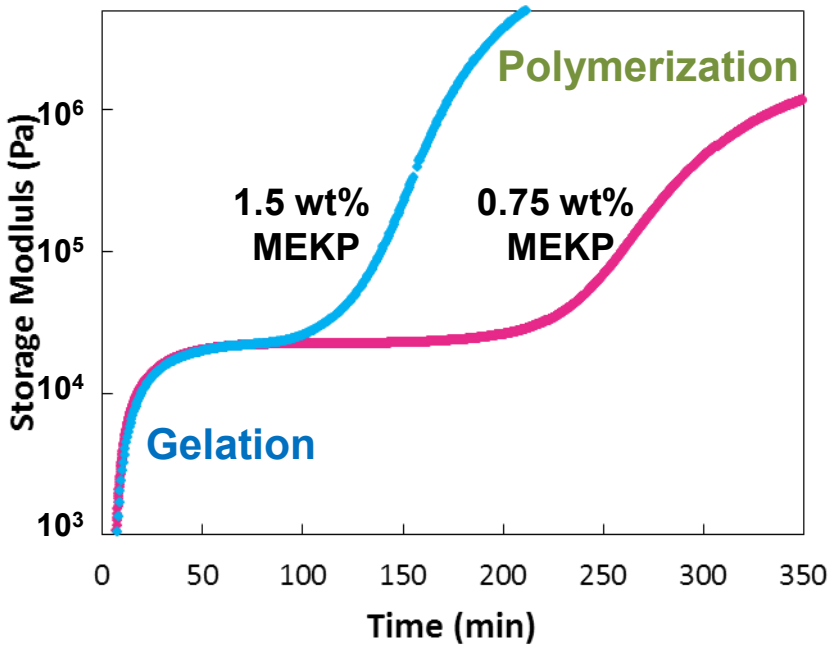
Controlled by acid catalyst & amount of gelators



t_2 Polymerization Time

Room Temp. Polymerization Components

- **Initiator – MEKP**
- **Promoter – CoNp**



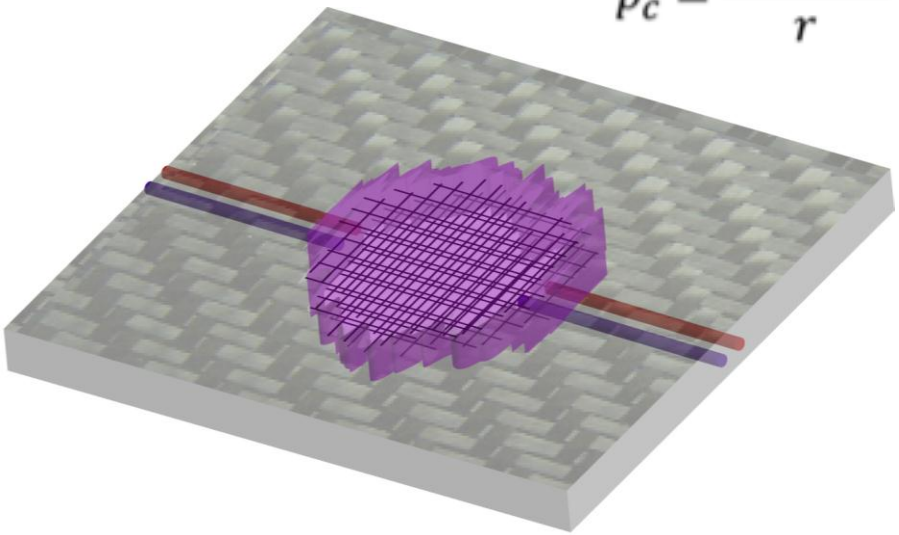
Polymerization: 0.3 wt% CoNp rs
15 v/v% acetic acid catalyst

Scaffold for Large Damage Volume

$$p_c = \frac{2\gamma \cos\theta}{r}$$

Infiltrate Scaffold

- Small pores fill with resin due to surface tension
- Sufficient healing agent delivery possible smaller volumes



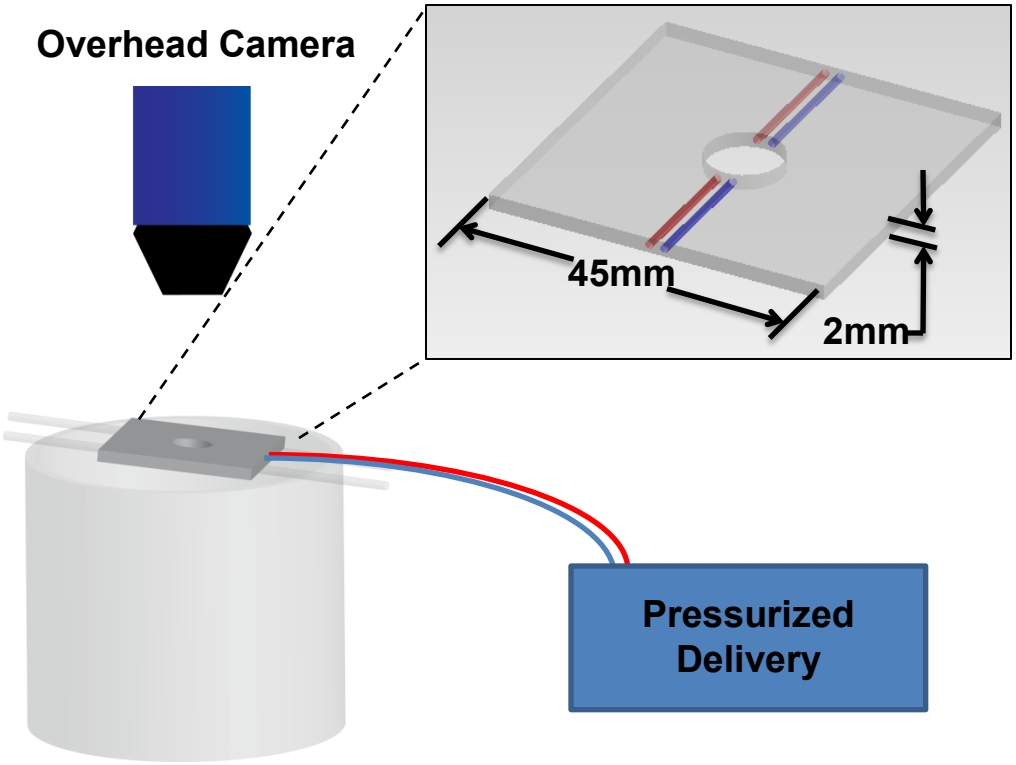
Gel Scaffold

- 2-component bi-phase gel/polymer system
- Gradual material deposition and solidification
- Gel network scaffold fills large volumes
- Subsequent polymerization and recovery of virgin properties

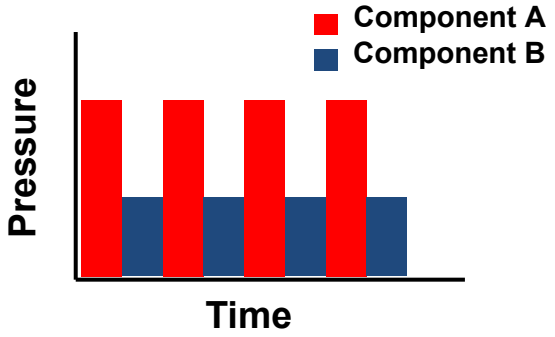
Part A	Part B
Monomer	Monomer
Acid Catalyst	Gel Part 1
Gel Part 1	Gel Part 2

Large Damage Volume Regeneration

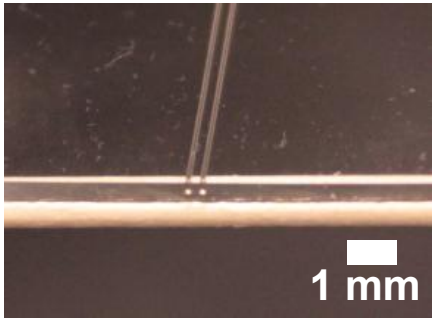
Damage Regeneration Setup



Damage Fill Pumping Regime

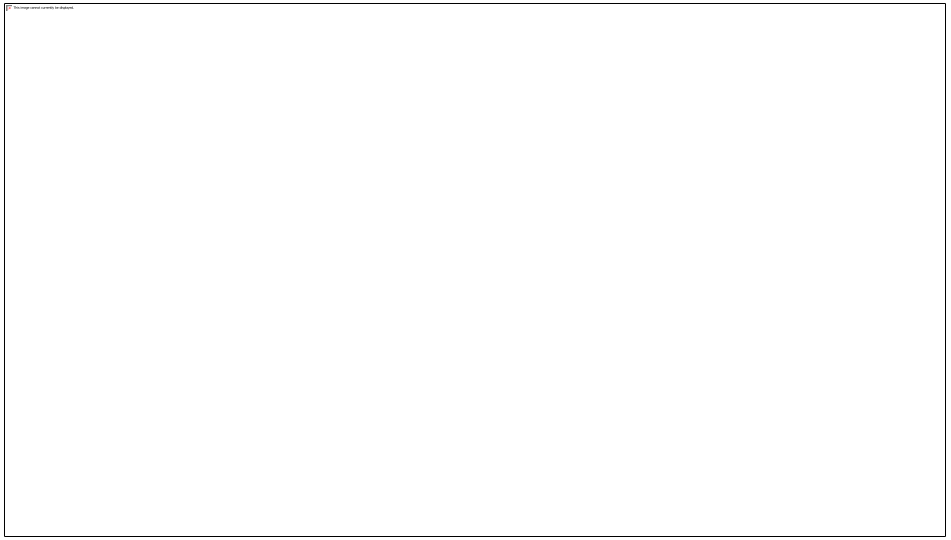


Microchannels in Specimen

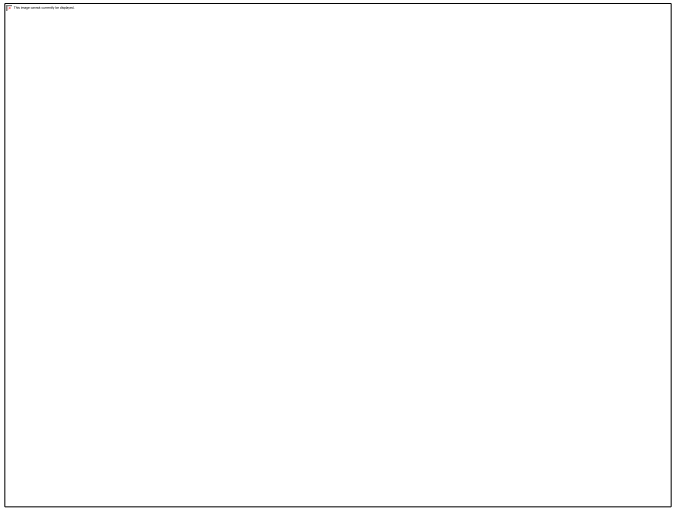


3.5 mm gap (PDMS healing system)

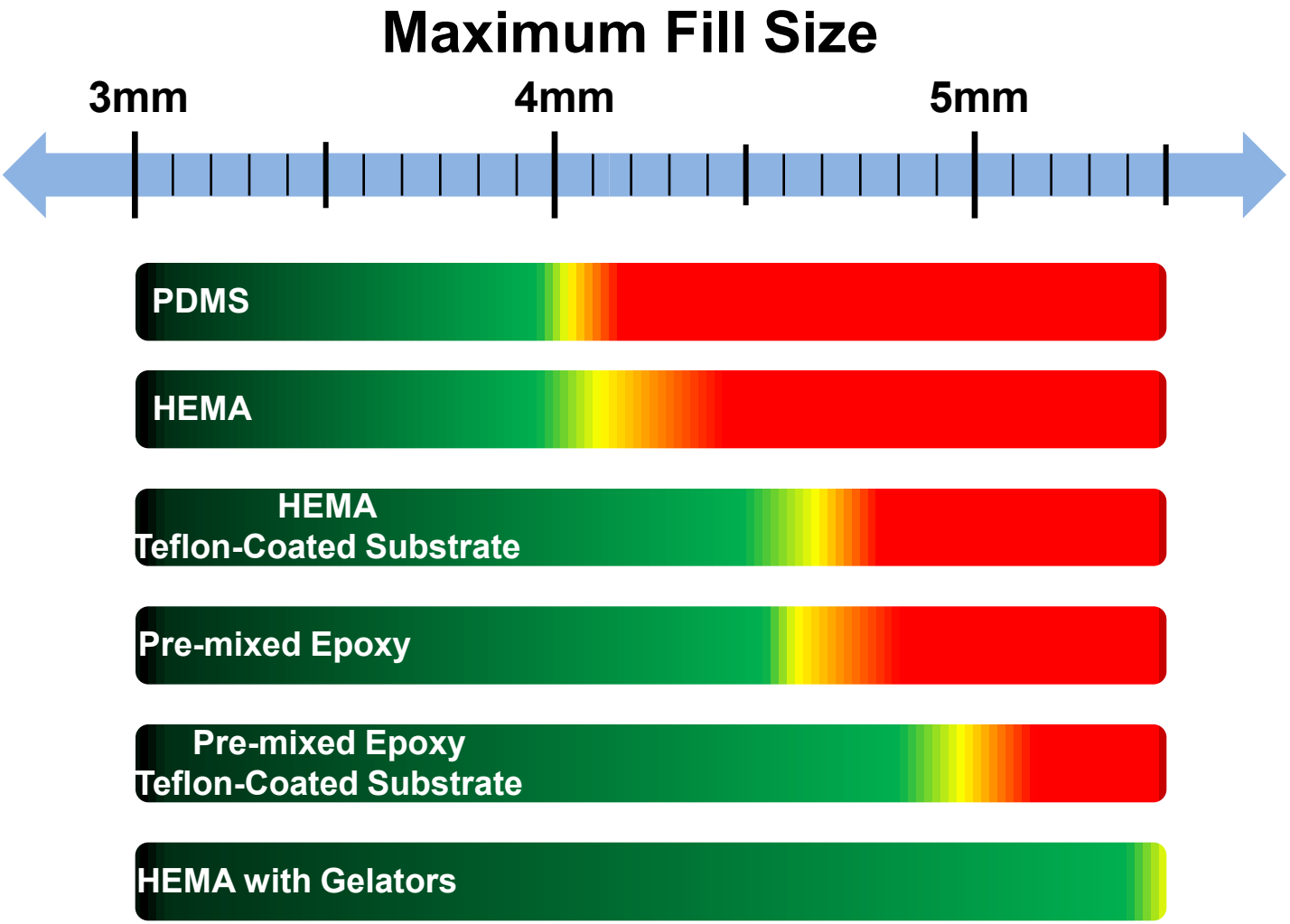
5.0 mm gap with bi-phase resin



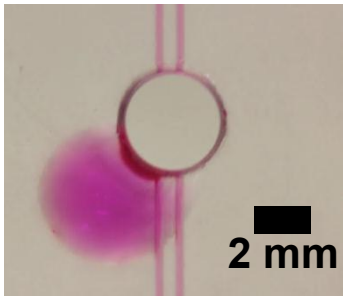
4.0 mm gap (PDMS healing system)



Damage Filling Results



Failure



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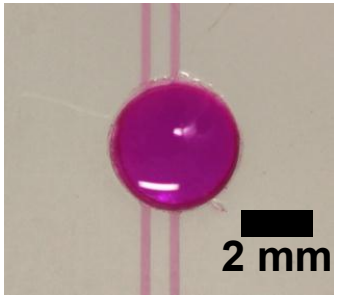
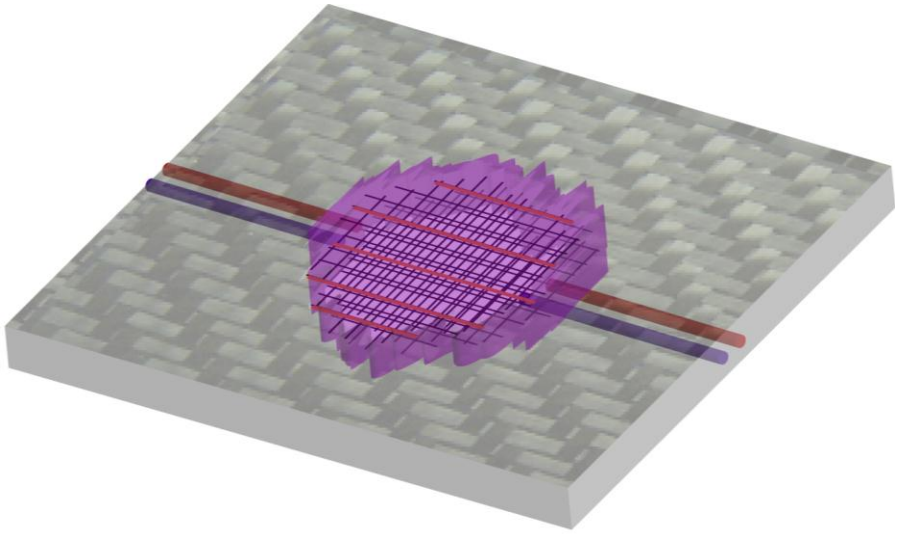


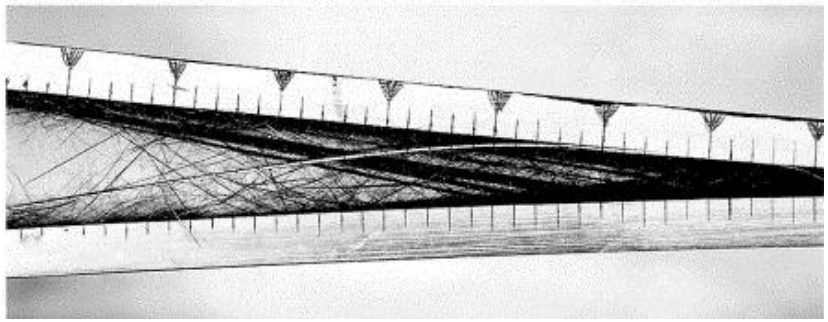
Multi-Scale Scaffold



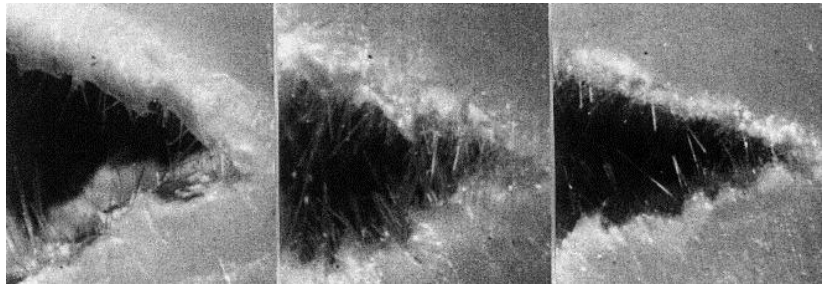
- **Concept:** Larger damage volumes can be regenerated using multiple scale scaffolds
- **Coarse Scaffold:** Fiber bridging/pullout
- **Molecular Scaffold:** Gel of bi-phase material

Fiber Bridging:

Carbon Fiber Reinforced Epoxy

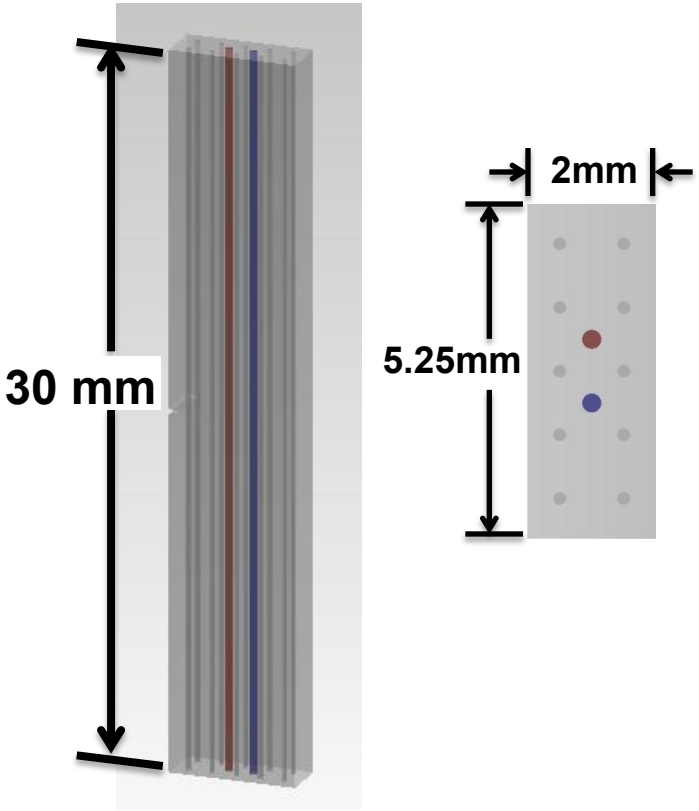


Short Glass Fiber Reinforced Nylon

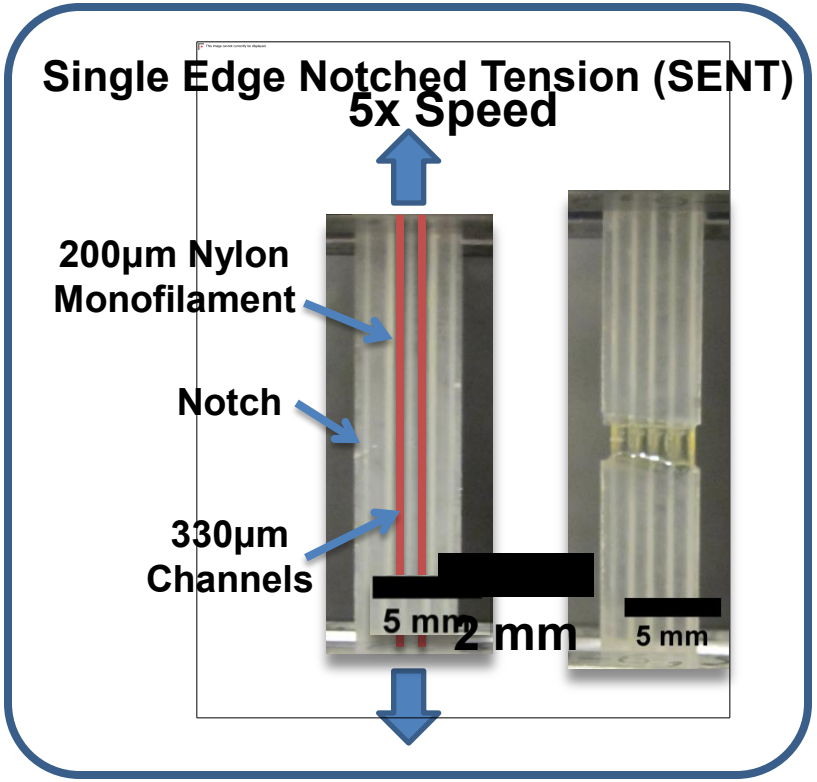


Segregation of Damage Volume via Fiber Pullout

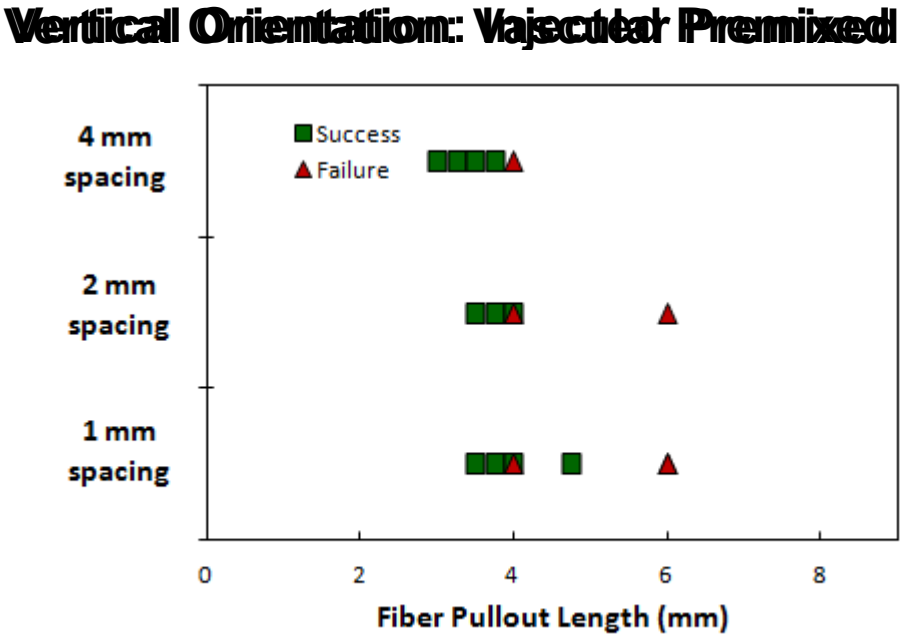
Specimen Geometry

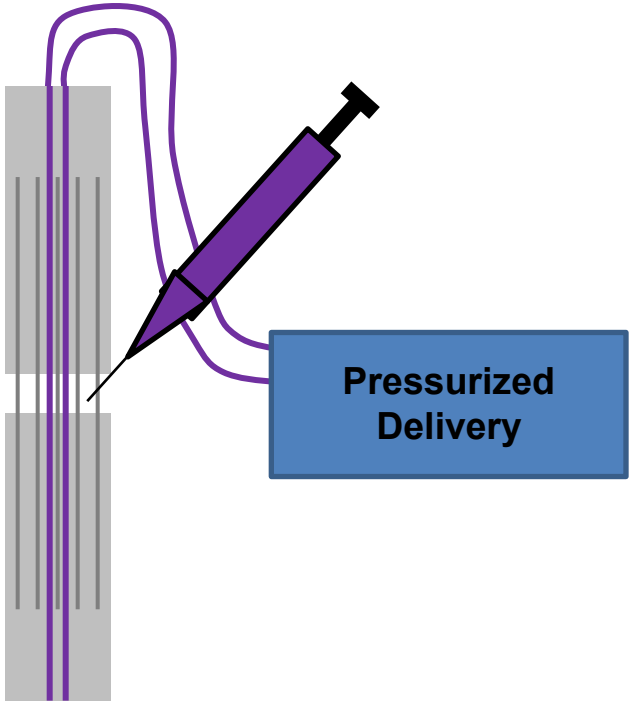


Single Edge Notched Tension (SENT)



Fill Testing of Bridged Region





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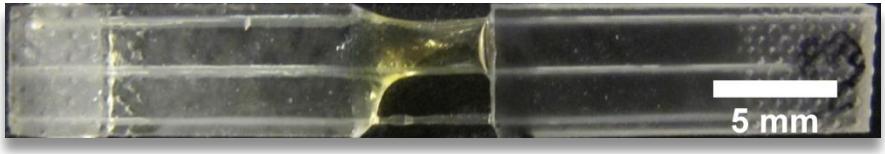

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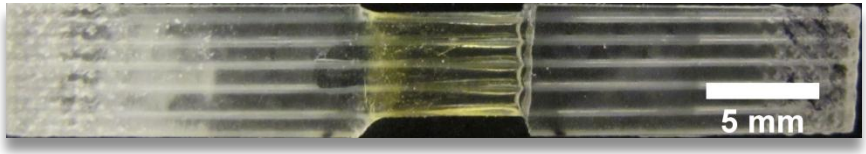
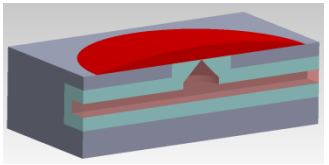
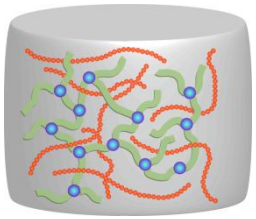


Summary

- **Embedded Valve Systems**
  - Mitigates blockage of network for multiple healing cycles
  - Autonomic delivery via pressure actuation



- **Bi-phase, 2-part Resin Chemistry**
  - Tunable kinetics for each constituent
  - Facile delivery of low viscosity, 2-part gel/resin system
  - Exceeds surface tension limitations to fill large volumes



- **Regeneration of composite materials**
  - Fiber bridging as vehicle for regenerative healing
  - Combined with bi-phase system, multi-scale scaffolds